Congestion-aware Rate Allocation
For Multipath Video Streaming
Over Ad Hoc Wireless Networks

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Outline

- Multipath video streaming over ad hoc wireless networks

- Congestion-aware rate allocation
  - Encoder distortion model
  - Network congestion model
  - Layered representation vs. partial repetition
  - Optimization: gradient descent

- Video streaming results
Video Streaming Over Wireless Ad Hoc Network

- Ad hoc wireless network:
  - No fixed infrastructure
  - Each node can be a source, destination or relay
  - Limited bandwidth and power, adverse channel conditions

- Real-time media applications:
  - Search-and-rescue, highway automation, etc.
  - High rate and delay constraints
Multipath Video Streaming

Benefits of multipath video streaming:
- Robustness to correlated packet losses
- Resilience to link failure
- Expansion of available bandwidth

Need rate allocation among different paths for scalable video bitstreams

[1]. Apostolopoulos, 1999
[S. Mao et al., 2003]
[E. Setton et al. 2004]
Problem Statement

- Rate allocation of embedded video bitstreams over multiple paths, one group of frames at a time

- Objective: to minimize expected video distortion at the decoder

- Constraints:
  - Total rate constraint
  - Upper and lower limit for each video frame
  - Transmission rate constraint on each link
Wavelet Video Coder

Original video frames

Temporal Wavelet Transform

Spatial Wavelet Transform

Embedded Quantization & Entropy Coding

Scalable bitstream

Encoder Distortion Model

- Distortion-rate function modeled as sum of exponentials

\[ d_{\text{enc}}^{(1)}(r) = \sum_{i=1}^{N} c_i \exp(-\alpha_i r) \]

- Sample fit of the model

Low frequency band RD fit

High frequency band RD fit
Network Congestion Model

- Independent delay distribution on each path
- Congestion dominated by the bottleneck link
- M/M/1 queuing model for delay distribution

\[ P_m = \exp(-\beta_m (C_m - R_{avg,m}) T_{playout}) / B \]

- Playout deadline
- Packet size
- Residual channel capacity on the bottleneck link
- Correction factor for overestimate of the drop rate
Bitstream Partition: *Layered Representation*

- Non-overlapping information on each path
- Higher efficiency
- More susceptible to packet loss
- $D_{\text{enc}}^{(l)}(R_a, R_b) = d_{\text{enc}}^{(l)}(R_a + R_b)$
Bitstream Partition: *Partial Repetition*

- Repeating the starting part of the bitstream on both paths
- Sacrifice coding efficiency
- More robust to channel errors and packet loss
- \( D^{(l)}_{\text{enc}}(R_a, R_b) = d^{(l)}_{\text{enc}}(\max(R_a, R_b)) \)
Optimizing Expected Decoder Distortion

To find the optimal rate allocation matrix $R$:

\[
\begin{align*}
\text{Minimize :} & \quad D_{\text{dec}} (R) = f \left( D_{\text{enc}}^{(l)} (R), P_m (R) \right) \\
\text{Subject to:} & \quad R_{ml} \geq R_{\min}^{(l)} \\
& \quad R_{ml} \cdot R_{\max}^{(l)} \\
& \quad R_{\text{avg},m} = \frac{V_{fps}}{L} \sum_{l=1}^{L} R_{ml} \cdot C_m \\
& \quad m = 1, \ldots, M, \quad l = 1, \ldots, L
\end{align*}
\]

$D_{\text{dec}} (R)$ depends on encoder distortion, packet drop rate on each path, and the bitstream partition strategy.

Optimization method:
- Gradient descent with the Lagrangian multiplier technique
- Heuristic: proportional rate allocation according to residual capacity on each path: $R_{ml} / (C_m - R_{\text{avg},m})$ for all video frames
Video Streaming Experiments

- Video sequence:
  - Foreman QCIF video sequence at 30 fps, 300 frames
  - Scalable video bistream from 3-D wavelet coding
  - One-level temporal Haar transform
  - Three-level spatial bi-orthogonal 9/7 decomposition

- Network simulation in NS-2
  - A network with 15 randomly placed nodes
  - \( M = 2 \) disjoint paths, each with 4 hops
  - Link capacities calculated based on Shannon’s formula for AWGN
  - Cross traffic randomly fills up to 70% of link capacity
  - Propagation delay and random packet loss ignored
Video Results: Playout Deadline = 350ms

Sequence: Foreman QCIF (Y)
Sequence length: 300
Frame rate: 30 fps
 GOP length: 16 frames
Temporal transform:
  1-level Haar
Spatial transform:
  3-level bi-9/7
Playout deadline: 350 ms
Packet Size: 1000 bytes
Simulation time: 10,000 sec.
No. of realizations: ~30
Video Results: Sample Sequence

$T = 350$ ms, Layered representation

Optimal Scheme:
Rate: 302.29 kbps

Heuristic scheme:
Rate: 306.44 kbps
Video Results: Playout Deadline = 150ms

Sequence: Foreman QCIF (Y)
Sequence length: 300
Frame rate: 30 fps
GOP length: 16 frames
Temporal transform:
  1-level Haar
Spatial transform:
  3-level bi-9/7
Playout deadline: 150 ms
Packet Size: 1000 bytes
Simulation time: 10,000 sec.
No. of realizations: ~30
Video Results: Sample Sequence

T = 150 ms, Partial repetition

Optimal scheme:
Rate: 222.99 kbps

Heuristic scheme:
Rate: 225.67 kbps
Conclusions

- Proposed a rate-allocation scheme for streaming scalable video representation over multiple paths in an ad hoc wireless network.

- Incorporate both the encoder performance and network congestion in the optimization of expected decoder distortion.

- Compare two bitstream partition strategies: *layered representation* and *partial repetition*.

- Experimental results show improvement of 0.5dB in received video PSNR over a heuristic scheme for varying playout deadline and both bitstream partition strategies.